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(6) **RESEARCH LEADING TO THE ESTABLISHMENT OF PARAMETERS**

FOR

OMNI-DIRECTIONAL RESTRAINT AND/OR CONTAINMENT

FOR

[illegible] IN AIRCRAFT

(7) **FINAL ENGINEERING REPORT**

PREPARED UNDER CONTRACT ~~Now~~ 62-0555C (12) (13) NA

DEPARTMENT OF THE NAVY, BUREAU OF NAVAL WEAPONS

AIRBORNE EQUIPMENT BRANCH

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504 West Peace Street
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FINAL ENGINEERING REPORT
UNDER CONTRACT Now 62-0555C
RESEARCH LEADING TO THE ESTABLISHMENT OF PARAMETERS
FOR OMNI-DIRECTIONAL RESTRAINT AND/OR CONTAINMENT
FOR PILOTS IN AIRCRAFT

General

National Textile Research, Inc. has conducted studies to investigate various methods of restraining the human body system in an effort to determine the most practicable method and configuration utilizing broad woven fabrics and/or materials.

The investigation was conducted in such a manner to utilize omni-directional lines of force, both compression and tension for body restraint during accelerations from any possible angle of load or force onset.

Work was accomplished to provide parameters of restraint in any attitude and was not directed at any particular aircraft or end use.

Introduction

The investigations conducted under this contract were directed toward the establishment of methods utilizing broad woven fabrics to accept, dissipate, and distribute impact shock forces such as would be developed during sudden and abrupt changes in acceleration caused by crash, high speed maneuvers, and operational malfunction of various types of airframes.

These investigations have encompassed many purposes, including the following:

(a) to determine the feasibility of employing broad woven fabrics to effectively restrain, contain, and omni-position the body during abrupt changes in acceleration,

(b) to determine the design parameters necessary to provide lineal and/or area load acceptance of restraint garments

(c) to determine the fabrics and weave constructions best suited to this application

(d) to determine the fundamental requirements of body restraint with omni-directional capabilities

(e) to study the force distributions of the fabric as it relates to imparting loads to the body.

Statement of Work

Phase A - A study has been conducted to determine the minimum requirements of number and methods of attachment points

for load acceptance to provide omni-directional restraint. A geometric structure was designed and built which consisted of two intersecting tetrahedrons thus providing an omni-triangulated, strutted reference frame which comprised a grid for the installation of attachment lines to the garment. (see Figure 1)

A flight suit was modified in such a way that a lineal attachment band was incorporated around the periphery of the garment.

A human subject was placed in the garment and then attached to the reference frame by a multitude of attachment lines. The frame was then rolled about to many attitudes of body position and the subject's reactions recorded. The lineal attachment afforded body comfort in all attitudes except for head-down inverted vertical position. Discomfort was caused in this instance due to the fact that the garment was not tailored to fit and the subject would slide downward until held only by the collar of the garment.

Attachment lines were systematically removed and the tests were again performed until the least number of attachment lines affording restraint was attained.

There were initially a total of thirty-three attachments which were reduced to eleven at the completion of the tests. The eleven final attachment lines gave the necessary restraint conditions in each of the attitudes of body position. The

attachments were point attachments but located lineally on the garment. This gave evidence of lineal attachment as a desirable means for omni-directional restraint.

Phase B - An investigation was conducted in order to determine the fibers and fabric construction best suited to this application. The requirements of a fabric to be used in an application in which high load must be accepted and dissipated are as follows:

a) high tensile strength

b) low elongation

c) recovery after impact load

d) low hysteresis (load recovery)

e) balanced construction.

The fabric selected was Fortisan-36 Cotton blend, Style 3306, Celanese Fibers Company, Division of the Celanese Corporation of America. The specifications of which are as follows:

Yarn	800 denier, 0.8 tpiZ 800 filament Fortisan-36 28s/1 corded cotton warp TMZ 28s/1 corded cotton warp TMZ All three ends plied at 6 tpiS
Weave	2 x 2 basket

	Warp	Filling
Ends and Picks/inch	40	42
1" strip tensile, lbs.	395-441*	459-465*
Elongation %	22.0	18.6
Grab Tensile, lbs.	500*	530*

	Warp	Filling
Ozs./sq. yd.	13.5	
Width	54.2"	
Trapezoid tear, lbs.	72.6**	over 120**
Air permeability cu. ft./sq. ft./min. at 0.5" water gauge	26.4	

RH 56% at 70°F Instron Tester at 400% rate of strain.

* - All bad jaw breaks
** - At the figures given, tear is not complete to the maximum and it was impossible to prevent slippage in the jaws at the level quoted.

Fortisan-36, content - 68%

All preliminary garment design configurations utilized this fabric. As it will be shown later in this report, final garment design configurations would present no failure in excess of 16,500 pounds force input to the garment. This value greatly exceeded the design requirement of 8,000 lbs. force acceptability. The load accepted required less than the tensile strength that could be used successfully, thereby permitting a lesser weight fabric to be used to provide a garment which would give greater wearer comfort.

As a result, a fabric of Fortisan-Cotton blend of 300 pound/inch tensile strength and a fabric of 100% Fortrel, Celanese Corporation, polyester fiber of 300 pound/inch tensile strength were tested in each design configuration and were found to be structurally sound.

<u>Phase C</u> - Garment Design and Test Results

Utilizing the information established under Phase A, a restraint garment design configuration was fabricated incorporating lineal attachment and area loading. The lineal attachment band was fitted with metal eyelets at four inch intervals and was attached by reaving a cable through the eyelets. (this design configuration listed in test data (chart No. 1) as Model 5-15-62) (see Figure 2)

A 95th percentile anthropomorphic dummy was dressed with this garment and placed on a static test device and loaded hydraulically with tensiometers for static load determination. (see Figure 3)

This garment failed at the eyelets in that the cable oriented itself to the direction of loading, thus producing point or strip loading of the dummy. The eyelets separated and pulled out of the fabric exposing raw edges of the fabric to tear, causing failure.

In an effort to achieve lineal attachment, area loading metal plates were made and attached to the lineal attachment band by passing bolts through both plate and eyelet. Under load, the eyelets pulled out of the fabric producing tear. An additional plate was placed on the back side of the eyelets thus holding them in compression. Static tests in excess of 8,000 pounds force produced no failure in the attachment system. However, this attachment system would be difficult for service application due to the time involved for proper attachment.

It was then decided to change to the aluminum A-Frames which utilize welt compression and retention for the attachment system. These A-Frames have proven very satisfactory in both static and dynamic testing of the restraint garment. Figure 4 shows a comparative structural strength of the various systems used. Figure 5 is a detailed drawing of the A-Frame as it has been developed to date. Upon selecting the attachment system for test procedures, full cover garments were then designed and developed and static tests begun. The first model restraint garment (model No. 8-24-62) was fabricated from the Cotton-Fortisan balanced construction fabric with tensile strength 560 pounds/inch. The garment utilized a rear closure secured with a large Velcro patch and heavy-duty zipper. (see Figure 6) Static tests in excess of 8,000 pounds force produced no failure of any kind.

A dynamic test device which consisted of a frame and attachment system was designed and built which could be used in conjunction with the drop tower at this facility. (see Figures 7 and 8)

Dynamic tests were begun on restraint garment (Model 8-24-62). After an initial low impact shock to remove any slack from the garment and attachment systems, a series of eight consecutive high impact dynamic tests was conducted with a minimal put load of 3,000 pounds and a maximum of 8,550 pounds equal to an excess of 42 g's.

The force was read by means of mechanical crusher gauges which are calibrated in deformation vs. force. (see Figure 9) These values were checked by a peak acceleration recording accelerometer. Values from the two methods were within 10 per cent of the total indicated load.

The rear closure garment required assistance in donning and doffing. It is felt that the garment, in order to be more practical and usable, should be able to be donned and doffed unassisted. As a result, the garment was redesigned to incorporate a frontal closure. This closure was accomplished by the Velcro patch and heavy duty zipper. (see Figure 10, Model 12-21-62) This garment had peripheral lineal attachment along the side seams and shoulder restraint accomplished by D-ring attachments. Dynamic impact tests were accomplished and the garment withstood six tests with input ranging from 7,400 pounds to 10,500 pounds with no failure. (see test data, garment Model 12-21-62)

On garment Model 1-11-63 the lineal attachment band was extended around the entire periphery of the legs and torso body systems. Attachment is made by using five A-Frames. This garment accepted and dissipated dynamic loads in excess of 16,500 pounds force. (82.5 g's) (see Figure 11) The frontal closure was retained in this design configuration.

Model 1-11-63 was subjected to a series of five consecutive dynamic drop tests ranging from 12,150 to 13,650 pounds input force. There were no garment failures. (see Model 1-11-63, test results)

In an attempt to design a lightweight garment, a totally new design configuration was developed and designated Model 12-17-62. In this design a lightweight fabric, similar to the five ounce flight suit fabric, has been used for a covering garment. Web straps have been wound over the body segments in overlapping helices to form a variation of the "Chinese Finger Gripper." (see Figures 12 and 13)

The helices have been wound such that the junction points are the points of highest inward component loading as given by the Timeshenko ring tension formulae. The formulae gave an inward component of loading of 94#/inch^2 with an input load of 40 g's or 8,000 pounds. This is neglecting all frictional and tensional load dissipation which would be considerable in this application.

The web strap system may be thought of as a clavicle splint restraining the shoulders, a Chinese Finger Gripper restraining the torso and leg segments, and a fan patch attachment at the waist. The method used in joining the straps from the "shirt" to the "pants" and from there into the seat system gives a fan-patch type of attachment which

will prevent submarining under waist restraint. The resultant vector produced by the attachments would be at a 45° angle respect to both the torso and legs.

Static testing has shown that the design configuration used in the omni-directional restraint garment Model 12-17-62 allows proper action of the web strap helices in that the forces are evenly distributed and construction of the helices is form fitting with the inward component forces are applied in the least vulnerable portions of the body system.

Phase D - Inward Component Determination

The restraint garment in each design configuration has now been developed to the point that structurally it will withstand high shock impact loads in excess of 60 g's. Although the garment as a unit will withstand such loads, it cannot be that the wearer of the garment will survive.

It was felt that the manner in which the garment transmits loading to the body should be determined. A test procedure was developed using a fourteen channel oscillograph, pressure sensitive transducers with suitable amplifier circuity. (see Figure 14) The transducers were taped on the surface of the dummy and the garment placed over the transducers. This would give the inward component or vector of the total input load at any desired point on the body.

An analysis was made on the percentage of total input load transmitted normal to the body. Using a 50th percentile semi-anthropomorphic dummy, the effective area of the front half of the torso segment was found to be approximately 171 square inches. Assuming no losses in shear, elongation and force transmitted to structures, the total load imparted to the torso segment may be divided by 171 to give the computed average inward component in pounds/square inch. The average indicated inward component was determined by averaging peak loads recorded by the transducers placed over the front half of the torso. This value was assumed to be indicative of the force over the entire effective area of the torso. This assumption is necessary due to the fact that placing a blanket of transducers over the entire working surface of the dummy is impractical.

The percentage of calculated inward components were plotted against the total load imparted to the torso segment. All values were recorded during high load impact dynamic test procedures. The total load is expressed in pounds of force. Figure 15 is offered for each of the prototype garments utilizing broad woven fabrics.

The omni-directional restraint garment, Model 2-763-PP has lineal attachment bands along the side seams and shoulder D-rings. At a total load of 50 g's, the garment directs

approximately 60 per cent of load perpendicular to the body surface. The remaining 40 per cent of the load is absorbed by tensional, frictional, shear, elongations, and losses parallel to the body surface.

The restraint garment utilizing total peripheral attachment (Model 2-1363-TP) at the 50g level imparts approximately 80 per cent of the load normal to the body surface. This difference in garment performance may be attributed to the fact that the garment with shoulder D-rings has more tensional losses in the fabric lay and stitch patterns than does the total peripheral attachment garment.

This company has developed methods of fabrication utilizing re-inforcing tapes, pattern lay, folding operations and sewing techniques which can be employed in directing the input load to any desirable part or portion of the body. However, as physiological studies of human tolerance to impact load at various small areas of the body were not possible under this contract, the areas of greatest load acceptability could not be determined explicitly. Future research in the physiological tolerances to point loading of the body may provide the necessary information required for optimum protection against high impact shock.

The prototype garments are designed to distribute the greatest loads to areas of the body with underlying muscular

masses and/or supporting bone structure.

A comparison of inward component loading at an area of less than one square inch and a total g's imparted to the test dummy for each broad woven fabric garment is shown in Figures 16 and 17. Each line represents the same point or location on the torso or body at various "g" levels. The location of this and other points are shown in Figures 18 and 19 which are typical test reports. The slope of each line is determined by the structure and rigidity of the body at that point. (Note: The leg segments of the anthropomorphic dummy have become very soft as a result of a great many violent tests, and allows the transducers to sink into the leg thus giving a much lower value than would be normally recorded.)

The force curve for any transducer location (inward component vs. g's) approaches a straight line thus indicating a direct constant relationship at any level of "g" force loading of the inward component of loading.

A comparative evaluation of the MA-2 parachute harness, omni-directional restraint garment 2-763-PP (shoulder D-rings and side attachments), omni-directional restraint garment 2-1363-TP (total peripheral attachment), and omni-directional restraint garment 12-1762-HW (helical straps) was accomplished in order to determine the inward component loadings for a typical input force as a measure of the relative performance of each garment.

Each type of restraint garment was dynamically loaded by vertical drops from the drop tower. As far as was possible, each garment was loaded with the same input force.

As pointed out previously in this report, the legs of the anthropomorphic test dummy are very soft as a result of a great many violent tests and allow the pressure transducers to sink below the surface thus giving either no load indication or a value much lower than is actually transmitted to each leg segment.

The accelerations produced in the comparative study ranged from five to ten g's. In order that a more complete evaluation of the garments might be accomplished, test results are presented in units of inward component force at each point/ 1,000 pounds total input force. Based on the data presented in Figures 17 and 18 which indicate that the relationship between inward component and total input at each point is lineal, this method is felt to be indicative of the values developed at any input load to the garment.

The results of this study are presented in Chart No. 2 of the test results obtained during the course of this work.

The results of our comparative study indicate that the torso area of the body is subjected to higher inward component loading by the helical wound garment than either of the two other alternate prototypes but is considerably less than the MA-2 harness.

Conclusions and Summary

The research studies under this contract indicate that omni-directional restraint can be obtained in a seated position by the use of body peripheral lines of attachment with a minimum of five or six attachment points, or use of helically wound tapes with a minimum of six or eight attachment points. This restrains the upper and lower torso and legs of the wearer.

The research and testing programs accomplished under this contract have shown broad woven fabrics to be capable of accepting and distributing high impact shocks over the body and thus lowering the inward component of loading at any particular location on the body surface.

Impact loads in excess of 16,000 pounds or an equivalent to 80 g's for a 200 pound man have been accepted by the omni-directional restraint garment without failure.

The garment is comfortable during prolonged wearing periods and may be donned and doffed unassisted by the wearer. No external adjustments are required for fitting or assurance of optimum performance under sudden or abrupt changes in acceleration.

Methods of directing load into areas of greatest tolerance on the body surface have been developed and may be used to effectively raise the body tolerances to accelerative loads.

The basic requirements of restraining a human body with omni-directional protection to changes in acceleration have been determined and have been applied to garment design successfully.

Recommendations

Work should be continued in this area of endeavor with the following to be specific considerations:

The omni-directional restraint garment has been developed to the point where it is structurally capable of accepting very high impact loads. It is felt that the aesthetic values of appearance, comfort and wearability should be further developed.

Fabric investigations should be continued as the test programs have shown the present garment to be overstrength with the present fabric. New fabrics such as HT-1 Nylon, Fortrel, Dacron or other polyesters, and other fibers and blends should be studied in order that an optimum high strength, lightweight fabric might be developed.

Human test subjects could be used to establish the "feel" of the restraint garments so that the comfort and performance might be improved. A track or vehicle test system would be an effective means of conducting such tests.

The use of power retention inertia reels in an appropriate seat system could be an effective means of evaluation of the performance of the omni-directional restraint garment.

Physiological studies of body tolerance to impact force as a function of inward component loading at specific

body locations should be accomplished so as to provide a guide to the methods used in absorbing loads to different areas of the body.

ILLUSTRATIONS AND TEST RESULTS

OMNI-DIRECTIONAL RESTRAINT GARMENT
TEST RESULTS, Now 62-0555C

Garment Model	Type of Test	Load Recorded (Pounds)	Results of Test
5-1562-TP	Static load cable and eyelet attachment	4000	eyelets pulled out (band loading)
5-15622-TP	Static load transducers for inward component	2050 (torso only) maximum inward component 55#/in^2	
5-15623-TP	Static load eyelet bolted to plate	4000	eyelets pulled out area loading achieved
5-15624-TP	Static load plate on both sides of eyelets	8000	no failure
5-1462-TP	Static load cable and eyelets	3800	eyelets pulled out cable orient to load point loading of garment
6-2162-TP	Static load A-Frame attach- ment	5500	failure along stitch line
7-762-PP	Dynamic tower drop	8000	no failure (cemented suit judges impractical)

8-2462-PP	Tower drops	2750 5100 3575 6750 4825 8500 4500 8550	no failures
9-1062-PP	Tower drop	7300	Rashell knit fabric complete failure low strength fabric
L-621-PP	Tower drop	9000	no failure
L-262-PP	Tower drop	9700	no failure
Final Prototype 12-1762-HW	Static load	5250	no garment failure attaching system failed
12-2162-PP	Tower drops	9175 9050 10425 9650 7400 10500	no failures
1-1063-PP	Tower drops	10,500 14,950 12,450 15,450 16,200	no failures
1-11-63-TP	Tower drops	12,700 12,950 12,150 13,650 12,450	no failures

Final Prototype 2-763-PP	tower and drops inward component determination	7 cycles in excess of 12,000	no garment failure (final prototype) see Figure 10
Final Prototype 2-1363-TP	tower drops inward component determination	5 cycles in excess of 10,000 (maximum 16,500)	no garment failure see Figure 11

INWARD COMPONENT LOADS/1000 lbs. INPUT FORCE
(Vertical Drops)

No.	Transducer Location	MA-2*	2-763-PP	2-1363-TP	12-1762-HW*
1	right breast	4 lbs.	4 lbs.	5 lbs.	43 lbs.
2	left side	47	30	25	32
3	left breast	3	2	3	30
4	back right shoulder	72	13	17	23
5	center of back	36	10	23	10
6	left lower back	30	4	23	10
7	right lower abdomen	36	20	18	8

* transducers located under web straps

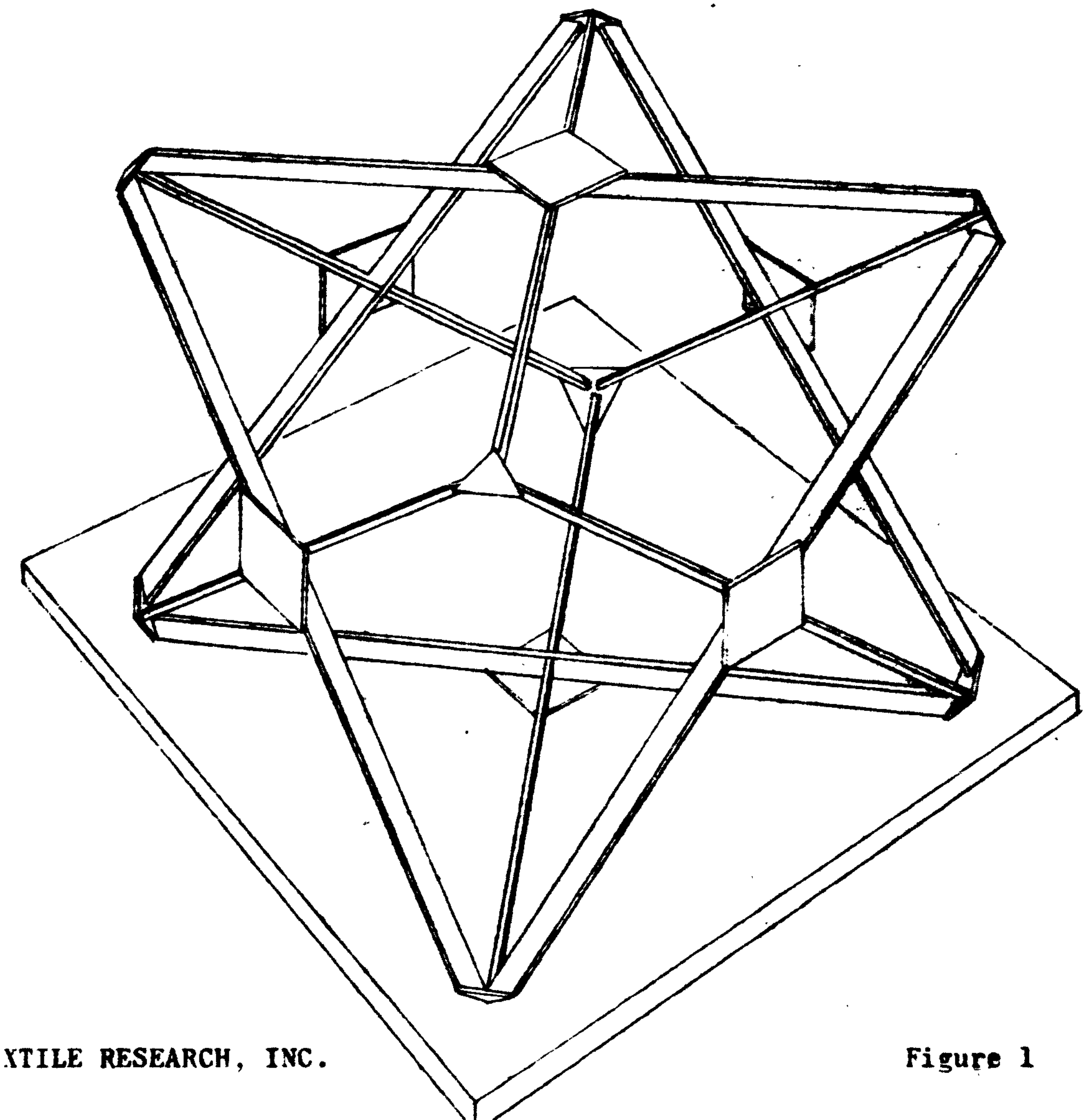

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Figure 1

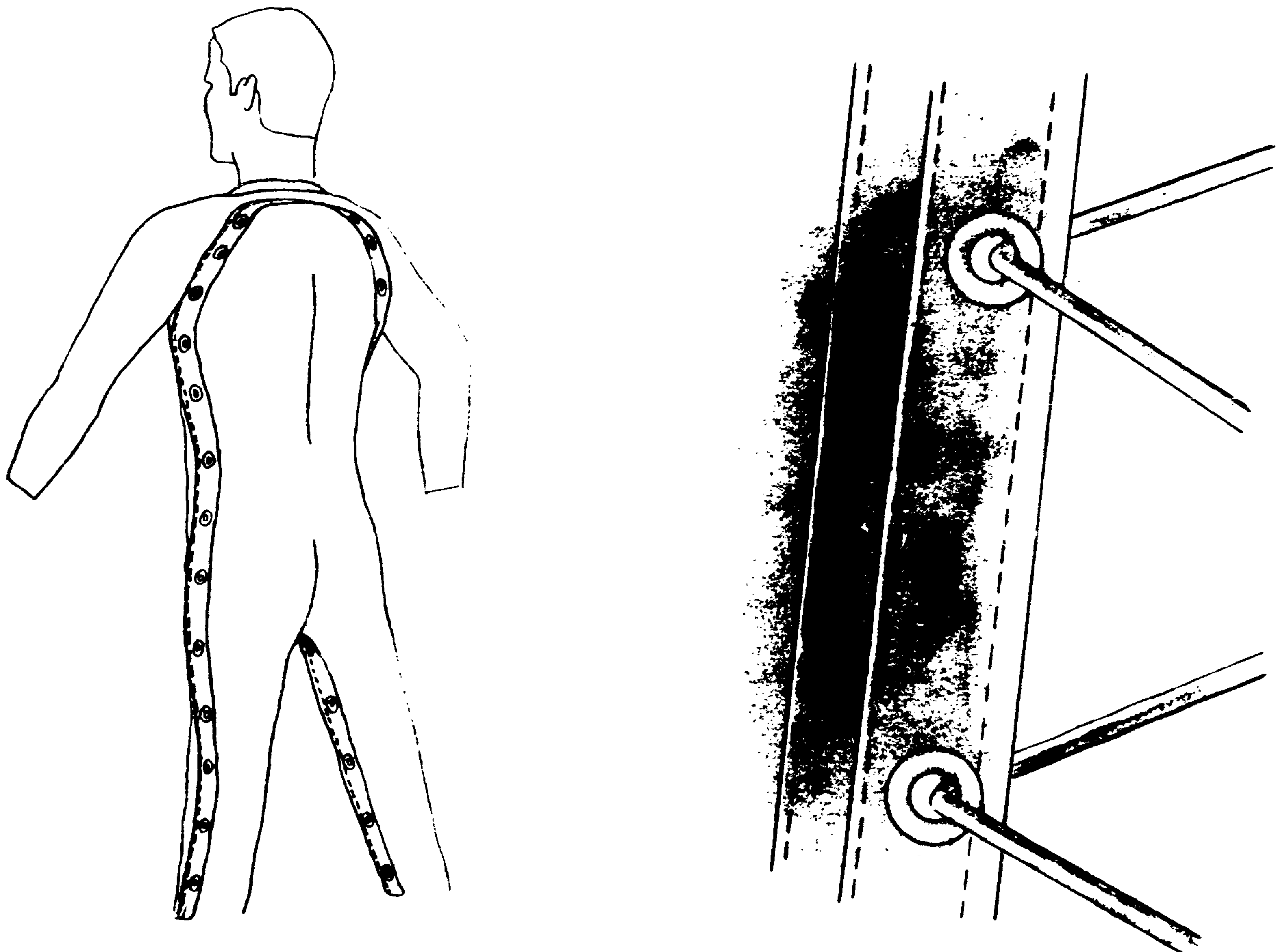

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Figure 2

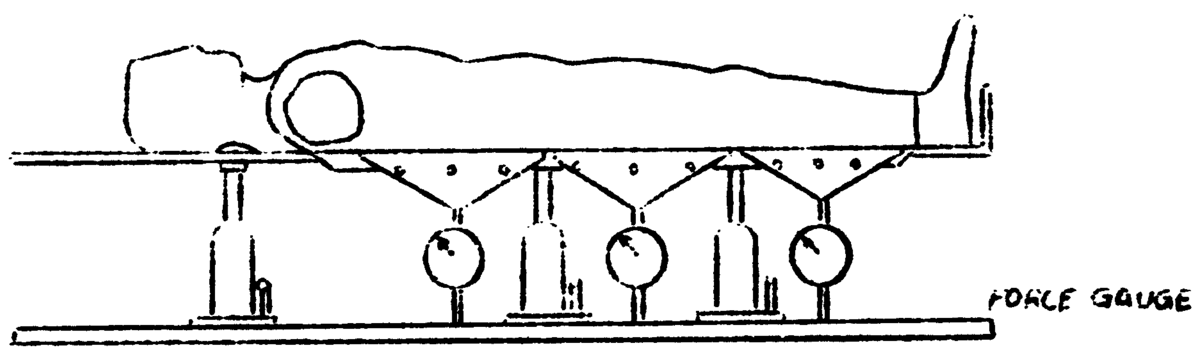

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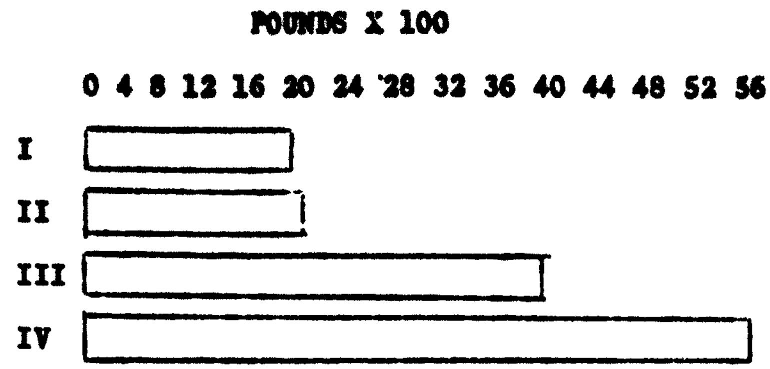
Figure ______



STRENGTH OF VARIOUS ATTACHMENTS

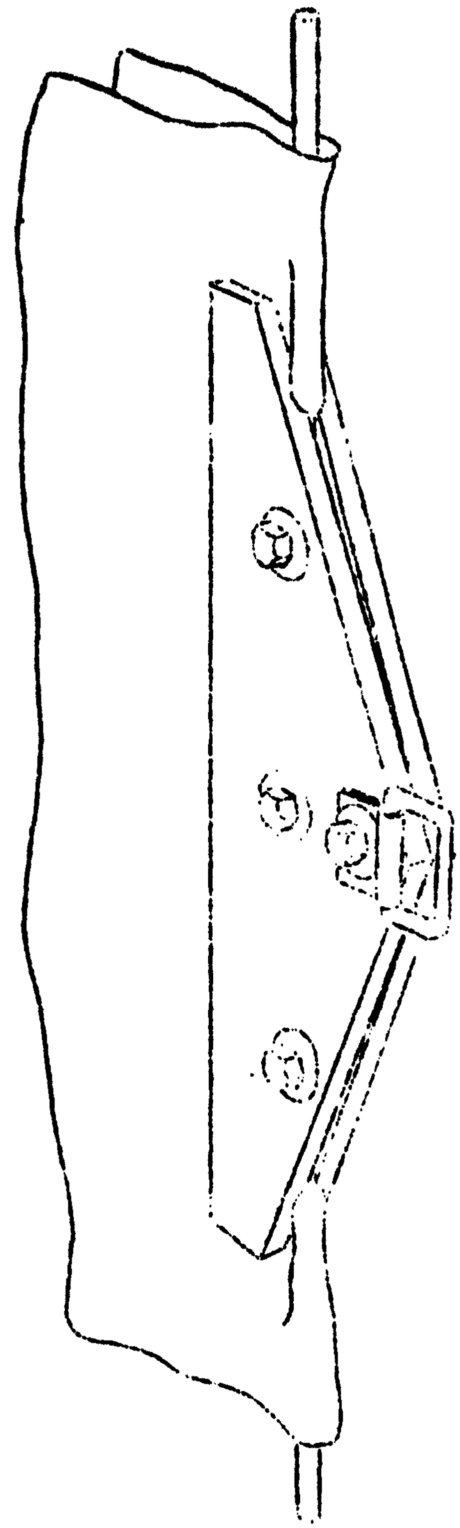
Type I: Cable laced in #2 spur grommet. (Eyelets separated)

Type II: "A" clamp bolted through #2 spur grommet. (Eyelets separated)

Type III: "A" clamp bolted through #2 spur grommet with back plate. (Compression on eyelets) (Eyelets pulled out)

Type IV: "A" clamp 3/8" grove bolted below the fabric, combination seam compression and welt tension. (Fabric broke, stitch line)

NOTE: ALL VALUES WERE TAKEN FROM THE UPPER TORSO



NATIONAL TEXTILE RESEARCH, INC. Figure 5

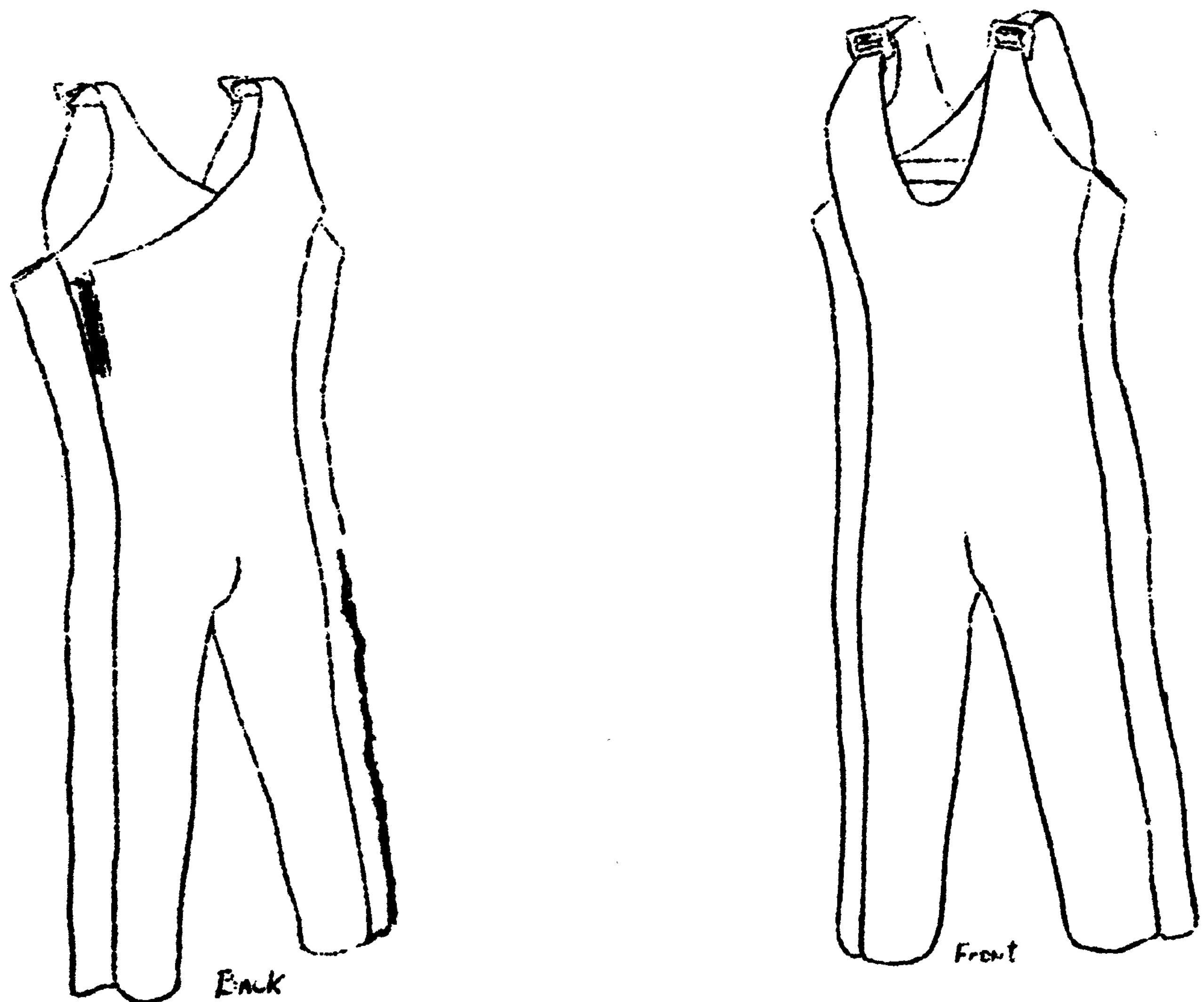
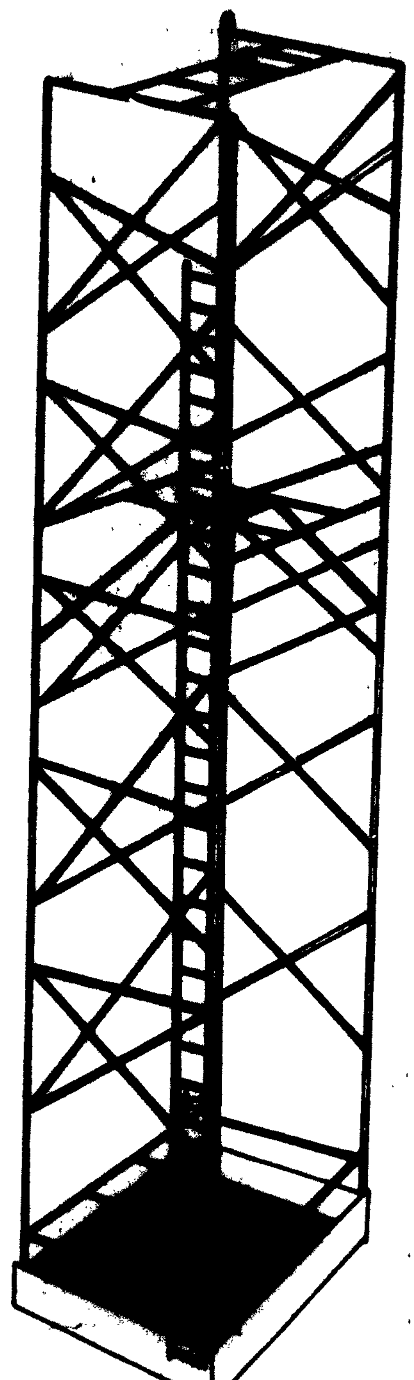


Figure 6



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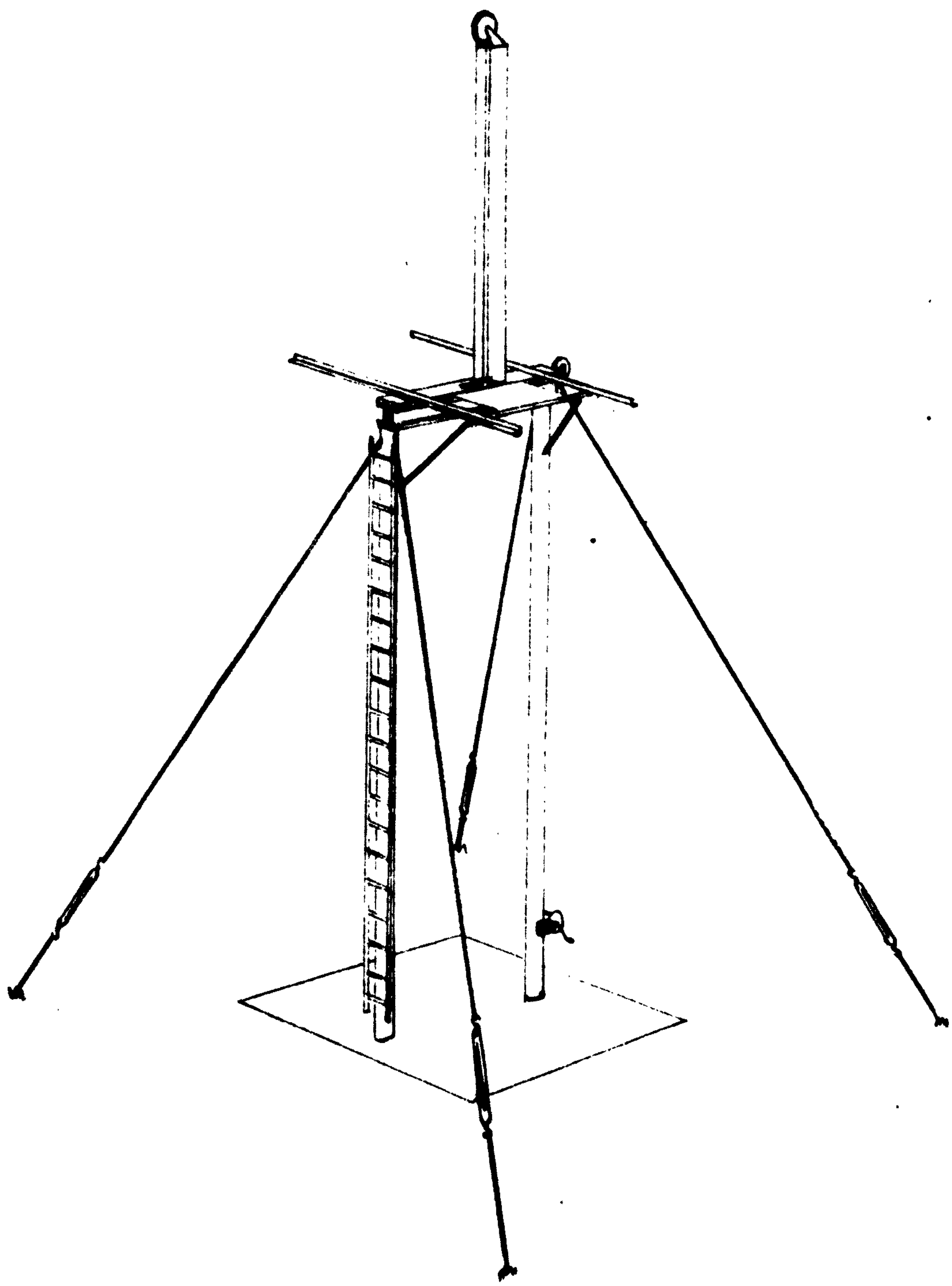

Figure

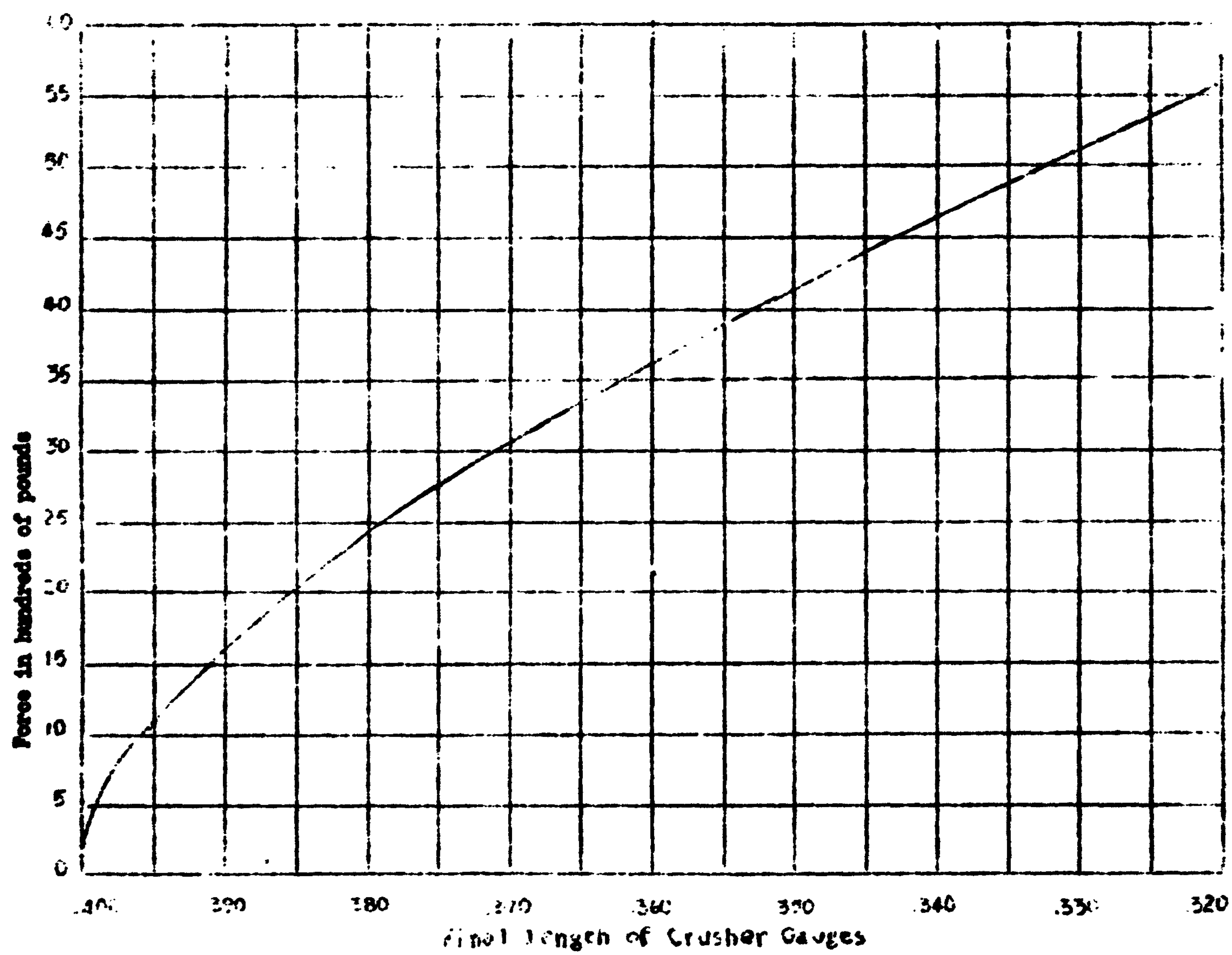

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Figure 9

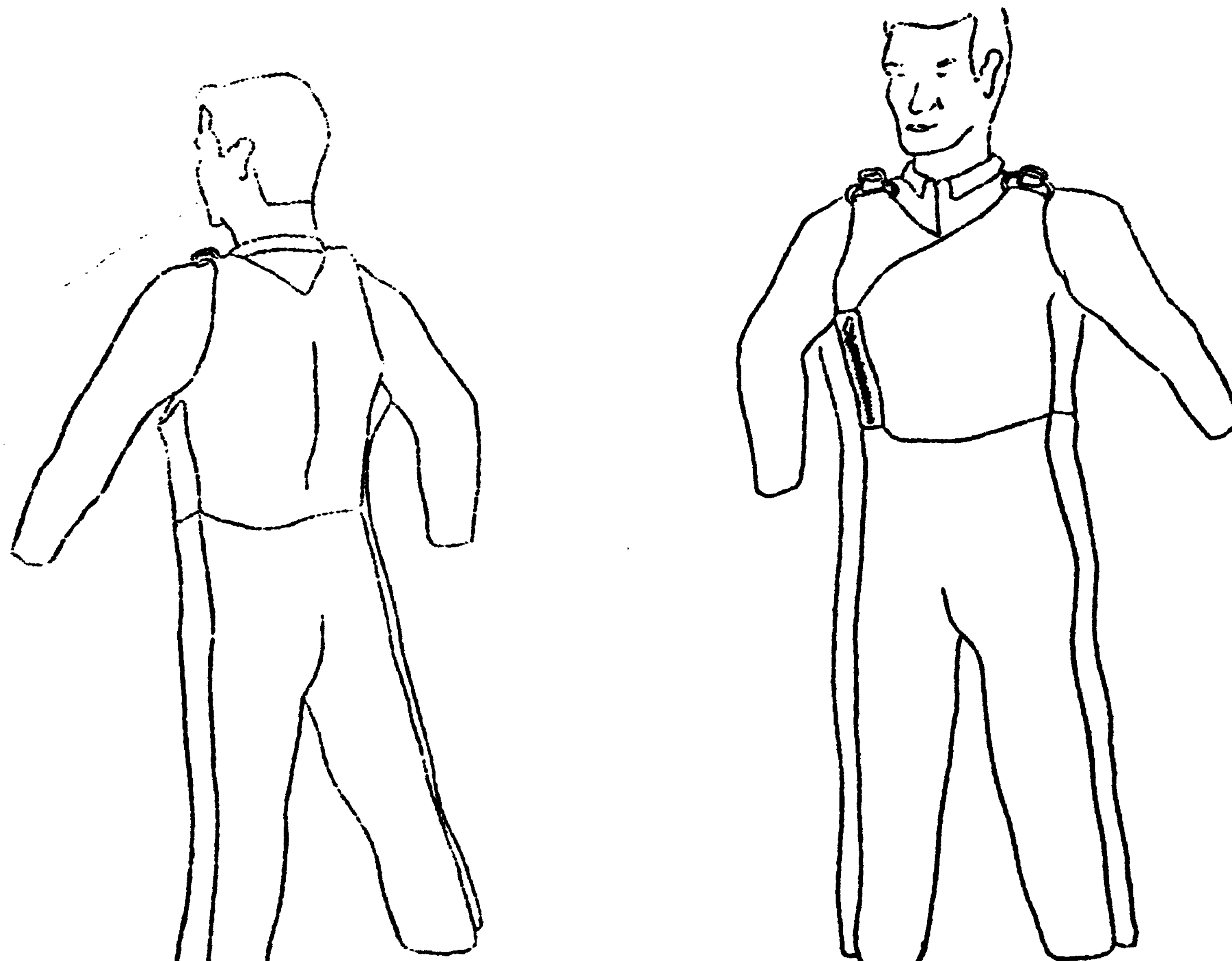

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Figure 15

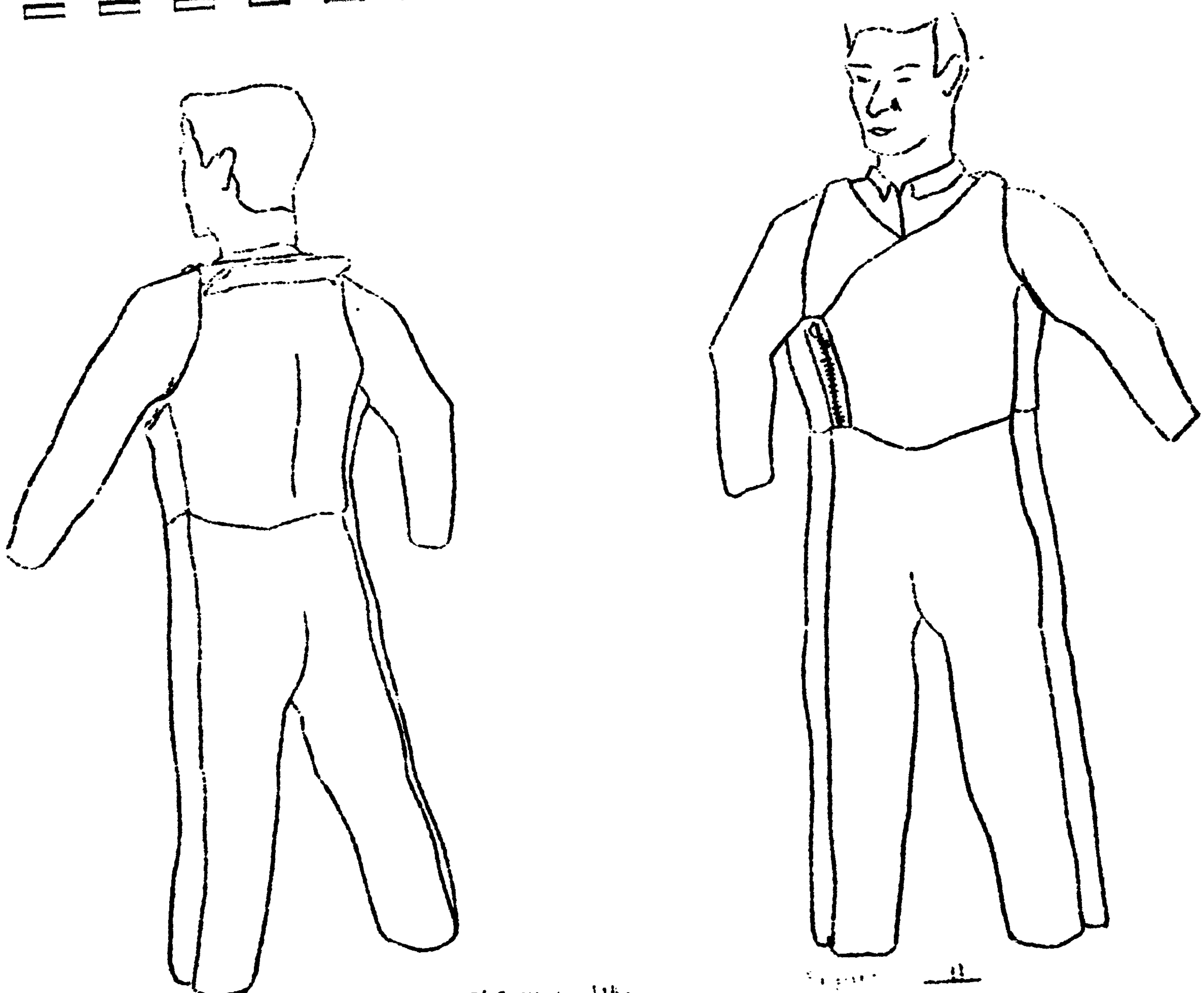

Figure 11

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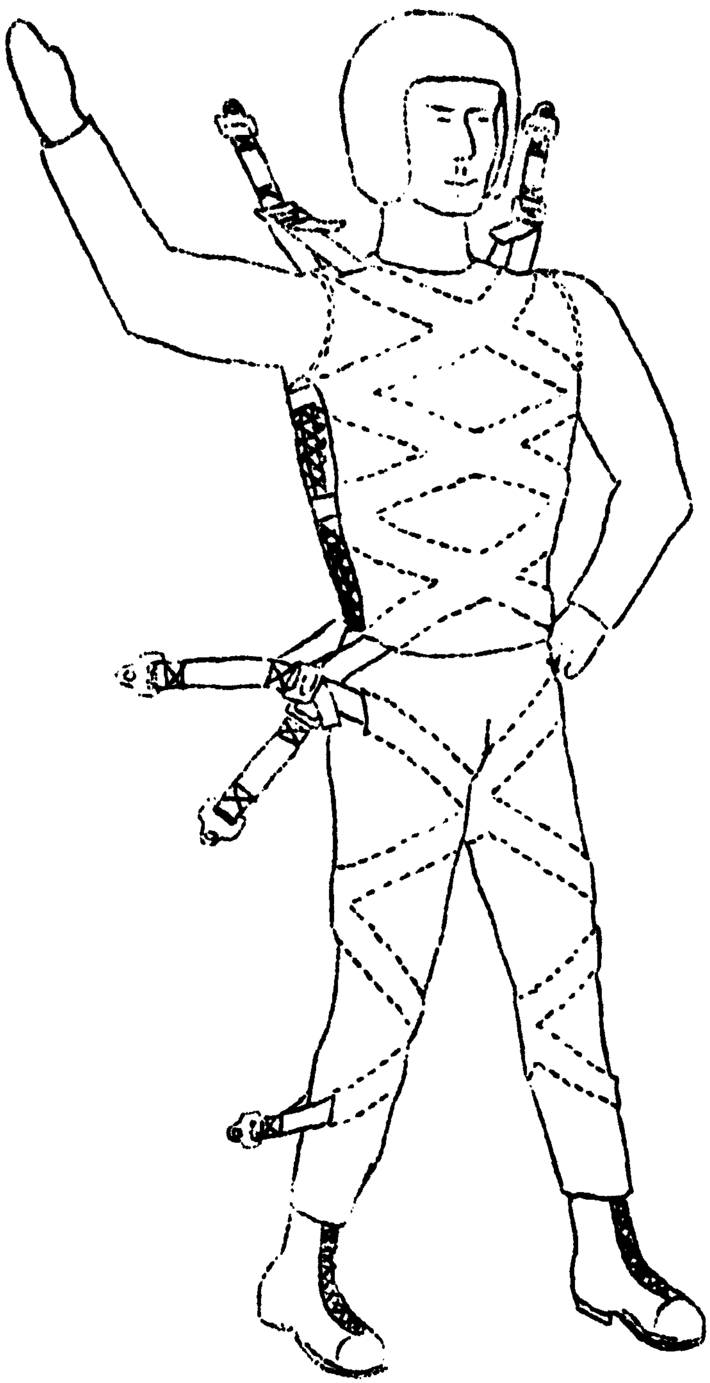

NATIONAL TEXTILE RESEARCH, INC. Figure 12

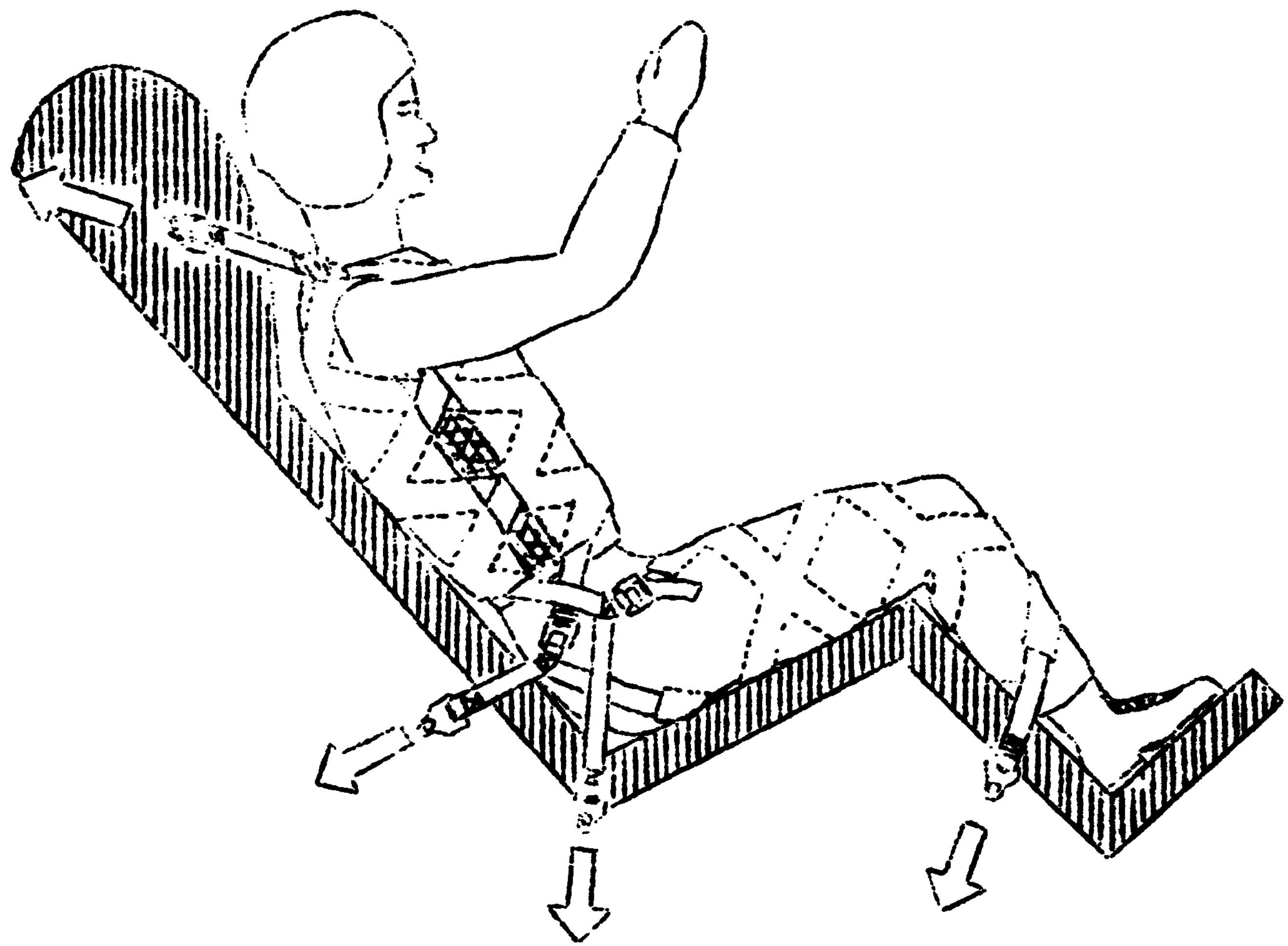

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Figure 13

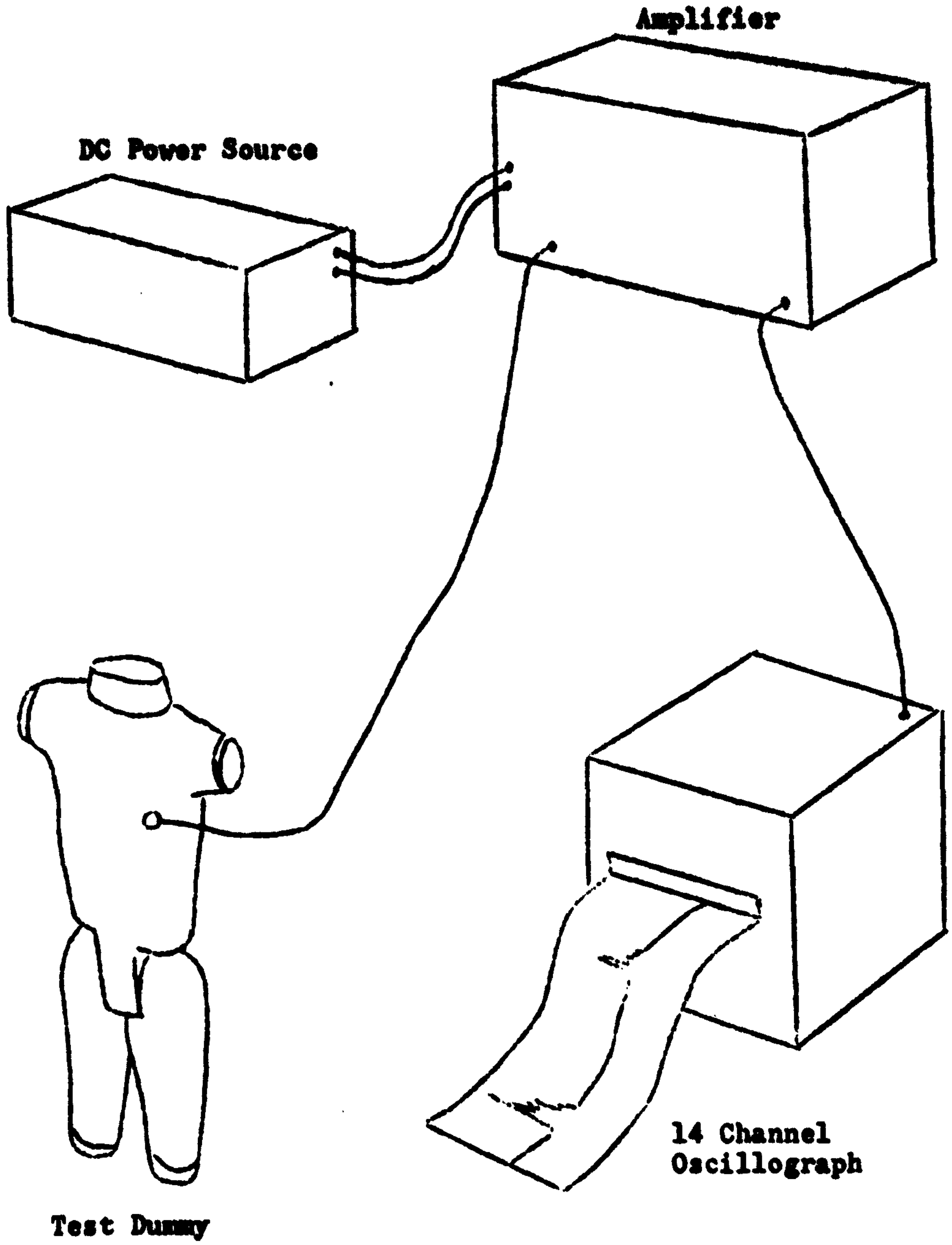

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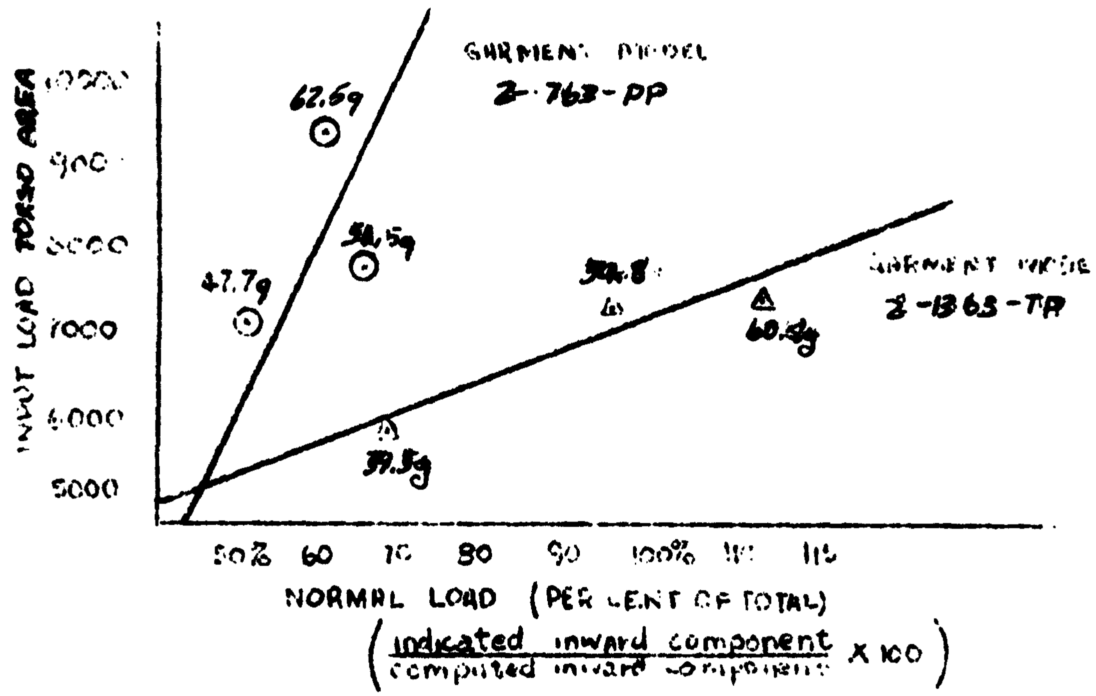
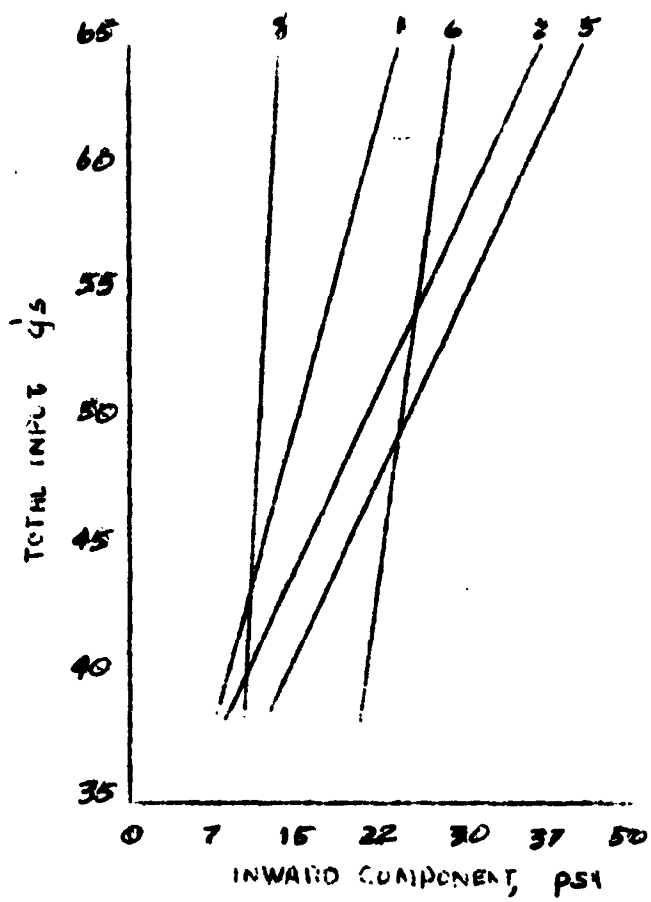
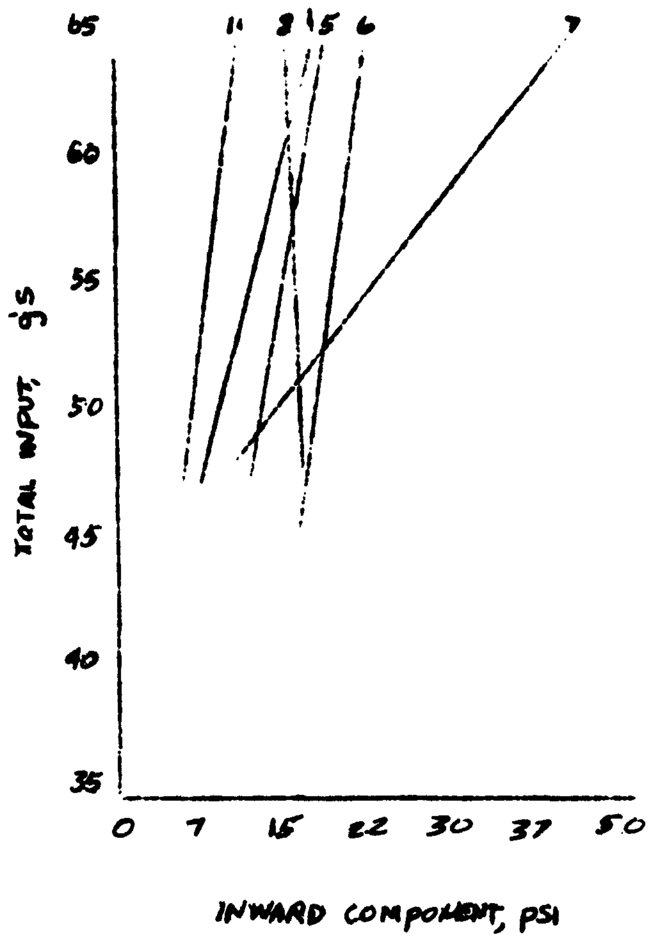
Figure No. 14



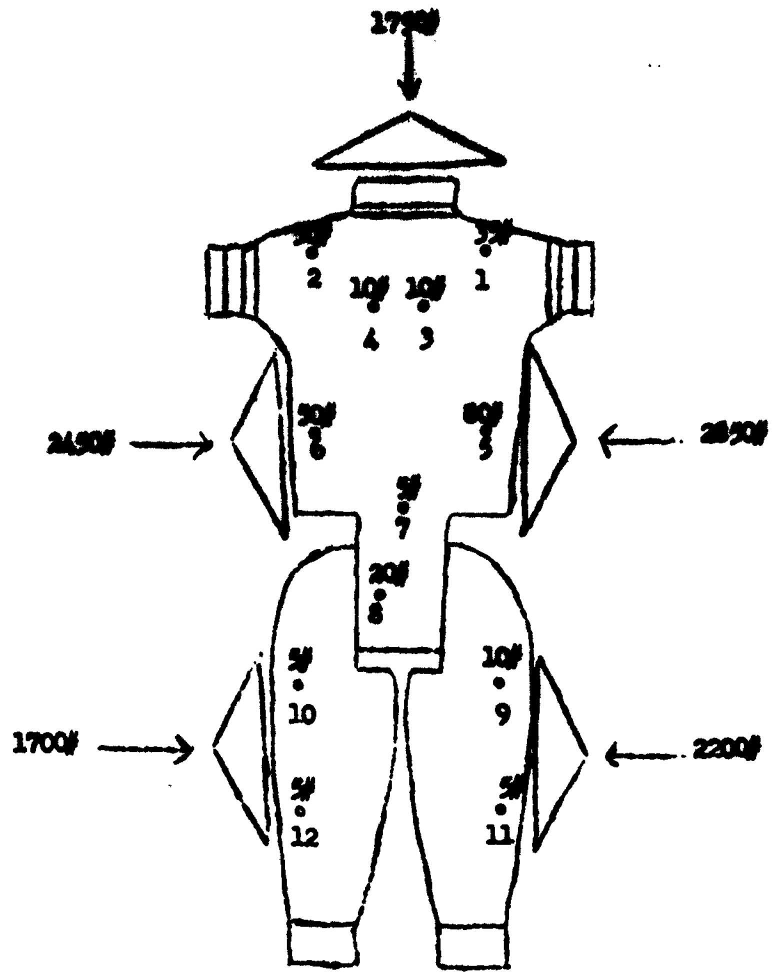
NATIONAL TEXTILE RESEARCH, INC. Figure 15



NATIONAL TEXTILE RESEARCH, INC. Figure 16



NATIONAL TEXTILE RESEARCH, INC. Figure 17



50th Percentile Semi-anthropomorphic Dummy
Transducer Locations

Height of drop - 3 feet

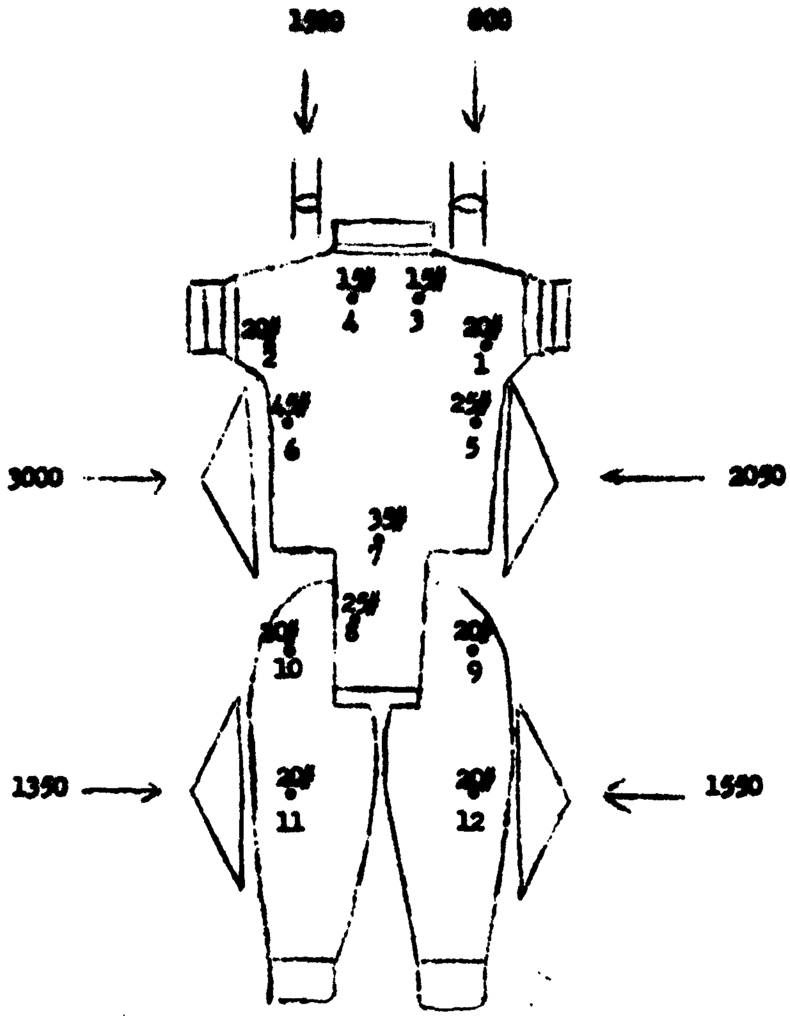
Total pounds force developed - 10950

Garment model - #2-1363-TP

Date - 2-15-63

Results of test - no garment failure

NATIONAL TEXTILE RESEARCH, INC. Figure 18



50th Percentile Semi-anthropomorphic Dummy
Transducer Locations

Height of drop - 3 ft.

Total pounds force developed - 10300

Garment model - 2-763-PP Omni-directional, shoulder D-rings

Date - 2-18-63

Results of test - #1 drop no failures

NATIONAL TEXTILE RESEARCH, INC. Figure 15